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Photovoltaic Testing Laboratory
Arizona State University's Polytechnic campus

Final Project Description Report

Proton Exchange Membrane (PEM) Fuel Cell Demonstration
Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers
Engineer Research and Development Center
Construction Engineering Research Laboratory
Broad Agency Announcement **CERL-BAA-FY03**

Silvestre S. Herrera US Army Reserve Center, Mesa, Arizona

12/31/2006

Executive Summary

Two Proton Exchange Membrane (PEM) fuel cell systems from different manufacturers (Plug Power and IdaTech) were used in this demonstration project at the Sergeant Silvestre S. Herrera United States Army Reserve Center in Mesa, Arizona, Building 602. The electrical power output capacity of the Plug Power system is rated at 5 kW_{AC}, with the IdaTech system rated at 4.5 kW_{AC}. However, the units were running at 2.5 kW_{AC} and 2 kW_{AC}, respectively, for the duration of the demonstration. Both fuel cells used natural gas as their fuel and are grid-connected. Both units provided combined heat and power (CHP), but the thermal energy use was not considered in this demonstration project.

Of interest in this demonstration is the ability of two fuel cells, made by different manufacturers, to operate well side-by-side during the required system demonstration time. Contract award for this demonstration is \$429,907. The local host site individual is Mr. James B. Cresto, Project Manager, 63rd RSC Engineer, whose e-mail address is Jim.Cresto@usar.army.mil. His cell phone number is 480-650-6164.

ASU-PTL did not expect a net gain on energy expenditures during this demonstration. However, a net gain of \$7,411 was noted based on natural gas and electrical energy bills from the year previous to the demonstration period. Reduced Army Reserve activity in the building was a major contributing factor, and so it is unclear how much energy savings could be attributed to the use of the fuel cells.

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Proposal – Proton Exchange Membrane (PEM) Fuel Cell Demonstration of Domestically Produced Residential PEM Fuel Cells in Military Facilities

1.0 Descriptive Title

A one-year demonstration project utilizing two different fuel cell units at the US Army's Silvestre Herrera Reserve Center, Mesa, Arizona.

2.0 Name, Address and Related Company Information

Photovoltaic Testing Laboratory, Arizona State University Polytechnic (formerly ASU East)
7349 E. Unity Avenue, Mesa, Arizona 85212
480-727-1220
DUNS number: 943360412
CAGE code: 4B293
Tax Payer ID number:

The Photovoltaic Testing Laboratory is a part of Arizona State University's Polytechnic campus, located at the old Williams Air Force Base, Mesa, Arizona. It functions to provide qualification testing services to manufacturers in the photovoltaic industry, and also serves as a third party testing laboratory for Underwriters Laboratories. It engages in academic activities by providing alternate energy classes to graduate and undergraduate students at the university. Included in these courses is instruction in the theory and practical applications of fuel cells. Practical, hands-on training is provided. The demonstration program at the Silvestre Herrera Reserve Center will give further opportunities for student involvement.

3.0 Production Capability of the Manufacturer

Product from two fuel cell manufacturers are used in this demonstration program.

First fuel cell supplier:
Plug Power of 968 Albany Shaker Road, Latham, New York 12110
Contact information:
Vincent Cassala
E-mail: vincent_cassala@plugpower.com
Ph : 518-782-7700 X 1228

Fuel cell was purchased with a 1 year warranty on all parts but repair labor was performed by ASU-PTL staff.

Second fuel cell system supplier:
Ida Tech, 63160 Britta Street, Bend, Oregon 97701
Contact information:
Tucker Ruberti
E-mail: truberti@idatech.com
Ph: 541-322-1046

Fuel cell was purchased with a 1 year warranty on all parts and labor. Many of the repairs were performed by ASU-PTL staff.

4.0 Principal Investigator(s)

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5.0 Authorized Negotiator(s)

Patricia Tennant
Sponsored Projects Officer
Arizona State University
480-727-1003

Dudley Sharp
Contracts Officer
Arizona State University
480-965-0273

6.0 Past Relevant Performance Information

(1) Project Title:
Establishment of a Fuel Cell Test Station

Project Experience:

A test station has been established to evaluate residential fuel cell systems at Arizona State University. This project involved three major tasks: Site development, Fuel cell system metering, and Fuel cell system installation. These major tasks included several subtasks including: construction of concrete pad; installation of awning, natural gas line, water line, wall mounted electrical service entrance along with protection units, LAN, internet based DAS, weather station, water and natural gas flow meters and electrical power meters; Mounting fuel cell system on the concrete pad, interconnection with local electrical grid and meeting the requirements of the local inspectors for gas and electrical connections.

Sponsor Name and Related information:

Salt River Project
P.O. Box 52025
Phoenix, Arizona 85072-2025
Point of contact: Ernie Palomino; E-mail: gepalomi@srpnet.com
Phone: 602-236-3014; Fax: 602-236-3407

Contract award date: 12/15/02 – 4/1/03

(2) Project Title:
Operation, On-Site Testing and Evaluation of a 5 kW Residential Fuel Cell System

Project Experience:

The fuel cell test station developed in the above project is now ready to be used to test a residential PEM, Proton Exchange Membrane, fuel cell system developed by a domestic manufacturer. This fuel cell system is commissioned and it is fully operational in both stand-alone and grid-connected modes. The primary objective of this project is to verify the manufacturer's performance claims and ratings. There are three major tasks involved in this project: Testing,

Data Collection and Data Analysis. A slightly modified protocol of EPRI "Residential Fuel Cell Testing Protocol for Grid-Connected Operation" is scheduled to be followed to test this fuel cell system. The tests include: Start-up operations, normal shut-down operation, steady state operation, transient load operation, part-load operation, sudden loss of load testing, short-circuit testing, overload testing and endurance testing.

Sponsor Name and Related information:
Electrical Power Research Institute (EPRI) and Salt River Project

Point of contact:
David Thimsen, EPRI
E-mail: dthimsen@epri.com; Phone: (651) 766-8826; Fax: (651) 765-6375
Ernie Palomino, Salt River Project
E-mail: gepalomi@srpnet.com; Phone: 602-236-3014; Fax: 602-236-3407

Contract award date: 01/01/03 – 07/31/04

(3) Project Title:
Fuel Cell Based Uninterruptible Power Supply (UPS) for Computers

Project Experience:
Arizona Public Service (APS), a local electric utility company, donated three fuel cell stacks, ranging from 250 W to 2000 W, for the research and development activities of Arizona State University. One of the H-Power PEM250 fuel cell stacks was chosen to power a single personal computer. After extensive investigation, appropriate dc-dc converter and dc-ac inverter were identified and integrated with the fuel cell stack and the computer. This UPS system is fully operational and it has been determined a full 2500 psi tank of hydrogen could support a single PC for about 40 hours.

Sponsor Name and Related information:
Arizona Public Service
Pinnacle West Corp.
P.O. Box 53490
Phoenix, Arizona 85072-3940

Point of contact:
Timothy McDonald; E-mail: Timothy.McDonald@pinnaclewest.com
Phone: 602-250-3032

Contract:
No funds were provided but APS donated several fuel cell stacks to ASU to support the research and development efforts of ASU

7.0 Host Facility Information

The host site is the Sergeant Silvestre Herrera US Army Reserve Center, 6158 South Avery Street, Mesa, Arizona 85212. Point of contact at the 63rd Regional Readiness Command, Los Alamitos, California is Dr. Michael Siu, Chief, Facility Engineering. His telephone number is 562-795-2060; e-mail is: Michael.Siu@usarc-emh2.army.mil. Local contact is Mr. James B. Cresto, Project Manager, 63rd RCC Engineer. Mr. Cresto's e-mail address is Jim.Cresto@usar.army.mil. His cell phone number is 480-650-6164.

The host site receives its electrical energy from the Salt River Project (SRP) and its natural gas feed from Southwest Gas. The Silvestre S Herrera US Army Reserve Center is located on the Arizona State University Polytechnic/Williams Gateway campus, at N33°18' latitude, W111°39' longitude, about 1,380 feet above sea level, and less than ¼-mile west of the Photovoltaic Testing Laboratory. It is a hot and dry climate, where the average high temperature in July is 104°F and the average low in January is 39°F, with an annual precipitation less than 10 inches.



Figure 7-1: Front sign of old Silvestre S Herrera US Army Reserve Center.

In early 2005, most of the Reserve Center activity was moved into a newly constructed building directly south of ASU-PTL. However, the fuel cell site is located at the old Reserve Center building. Figure 7-2 shows a drawing of the old Reserve Center site layout.

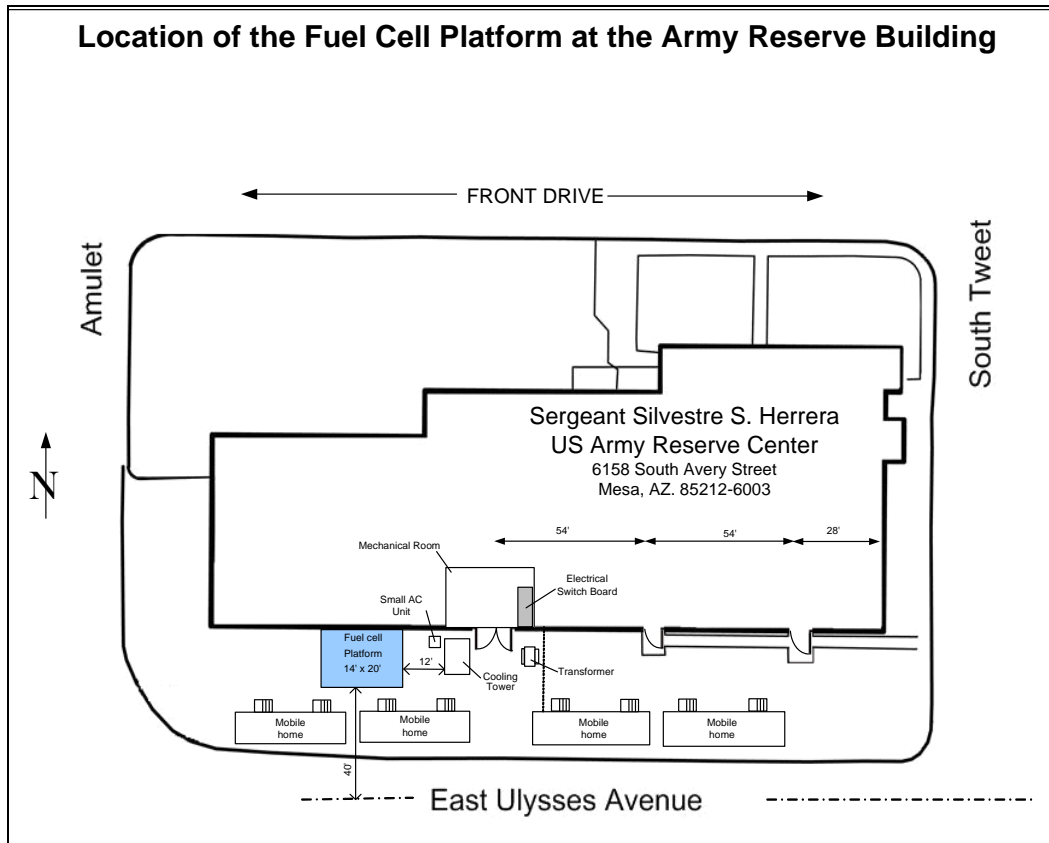


Figure 7-2: Site layout for fuel cell system installation.

The Plug Power and IdaTech system site requirements are listed in Table 7-1.

System	IdaTech nGen5	Plug Power Gensys
Gas pressure	3 to 11 INWC	4 to 11 INWC
Gas flow	< 40 SLPM	50 SLPM
Water pressure	Not specified	40 to 120 psig
Water hardness	Not specified	<15 grains per gallon
Electric	208 Vac, 60Hz	120 Vac, 60 Hz
Typical Environment	Indoor – 36°F to 104°F	Outdoor – 0 to 104°F, 10 to 90% RH

Table 7-1: System site requirements.

8.0 Fuel Cell Installation

In late 2004, an awning and fence were constructed on the south side of the old Silvestre S. Herrera US Army Reserve Center building. The awning was built to provide some shading to protect against the extreme summer days in Mesa, AZ, which can exceed temperatures of 110°F. The fence is a simple deterrent for curious passers-by. The construction of the awning was contracted outside and was completed in September 2004. The fence was installed by ASU-PTL on September 17, 2004. Figure 8-1 shows the awning and fence in place before the systems were installed.



Figure 8-1: Awning and fence built and ready for fuel cell systems.

8.1 Platforms

Prior to installation, ASU-PTL constructed two mobile platforms, each with compatible hook-ups for natural gas, water, and electrical delivery. Each fuel cell system was placed on its own platform. The Plug Power fuel cell system arrived at ASU-PTL on August 2, 2004, and was secured to its platform on August 13, 2004. The IdaTech unit arrived at ASU-PTL and was secured to its platform on November 30, 2004.

Each platform is equipped with a deionization (DI) water treatment plant (provided by each respective fuel cell manufacturer), a data acquisition system, a large plug for the AC electrical connection, gas and water flow meters and transducers, gas and water pressure meters, and adjustable legs for site balancing. A mockup drawing of the platforms is shown in Figure 8-2.

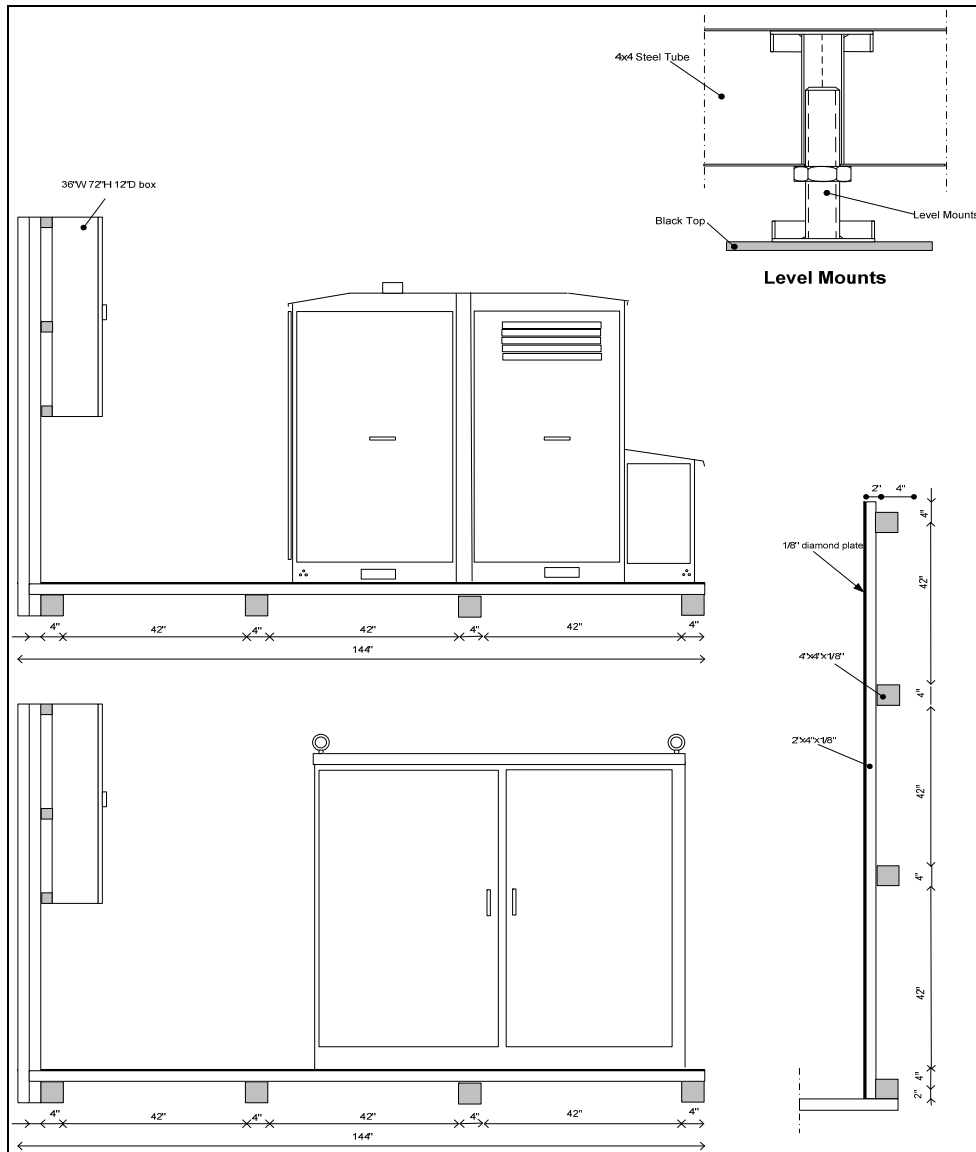


Figure 8-2: Fuel cell platform mock-up drawings – Plug Power on top, IdaTech on the bottom.

The idea for the platforms is educational in nature. After the completion of the CERL system demonstration, the platforms and fuel cell systems will be transported back to the lab to serve as a teaching tool in the university's alternative energy program.

A snapshot of the platform construction is shown in Figure 8-3. Figures 8-4 and 8-5 show the IdaTech and Plug Power systems mounted on the platforms at the lab, respectively.



Figure 8-3: Fuel cell platform construction.



Figure 8-4: The IdaTech system on its platform at the lab. A nitrogen bottle is hooked up for a gas pressure/leak check.



Figure 8-5: The Plug Power system installed on a test platform.



Figure 8-6: Beginning to move the Plug Power platform.

Once the fuel cells were placed on the platforms, they were moved, via forklift (Figure 8-6), to the Silvestre S Herrera US Army Reserve Center. The systems were then connected side-by-side, with the Plug Power unit being installed first. The lab purposely delayed installing both systems simultaneously. In case problems were encountered with the first system, the lab could work to solve them before the second one was in place.

Once the platforms were installed, the connections were made. The electrical connections were made by fitting two large outdoor plugs into a special 240Vac outlet, hard-wired by ASU-PTL prior to installation. The gas connections were form-fitted with black pipe, and the final water connection was welded. The total time to install each system was approximately 100 man hours. This included the copper pipe, electrical, and data acquisition requirements.



Figure 8-7: The two fuel cell systems installed at the US Army Reserve Center. The outdoor AC plug is projected.

8.2 Commissioning

Lab members attended a week-long course by Plug Power on Gensys 5C commissioning procedures. The fuel cell stack was installed at the lab by ASU-PTL. Two system coolant loops were filled – propylene glycol for general system heat transfer, and Therminol for the fuel cell stack. AC electrical connections were made, and the 48 Vdc battery bank was connected. The system was started up initially in Manual Mode by pressing the Start button on the unit. Once in Manual mode, the Plug Power Gensys could be commanded through its Service Interface Software on a local laptop computer, shown in Figure 8-8.

The IdaTech system was commissioned at the site by IdaTech engineers. ASU-PTL fuel cell staff was on hand for support. The commissioning included finishing the gas-line plumbing, installation of the inverter and fuel cell stack, and setting up remote communications through a firewall and satellite network. This commissioning time also served as operational training for ASU-PTL.



Figure 8-8: Dedicated laptop for data collection and commanding the Plug Power system. Plug Power's Service Interface Software is shown.

8.3 Operational Settings

The Plug Power Gensys has three basic power dispatch settings: 2.5 kW, 4 kW, and 5 kW. Based on previous experience with a Plug power Gensys, the lab decided to run the demonstration exclusively at the 2.5 kW setting. It was concluded that the unit would run more reliably, for a longer period of time, at the 2.5 kW setting in comparison to 4 kW and 5 kW.

The IdaTech system can be set at multiple power dispatch settings, ranging from about 500W to 4.5 kW, based on the percentage of capacity chosen. The power dispatch for IdaTech is set remotely by IdaTech engineers. For the purpose of this demonstration, ASU-PTL requested a power dispatch setting of 2 kW for the IdaTech system (about 44% of its electrical capacity).

Both systems are considered as combined heat and power (CHP) plants, where the customer can make use of the waste heat generated as a hot water source or space heating. The lab chose not to make use of the CHP capabilities of either system during the demonstration. The systems are grid-connected without additional load.

8.4 Estimated Energy Savings

ASU-PTL does not expect a net gain on energy expenditures during this demonstration. Table 8-2 shows the net energy production, consumption, and energy costs expected during the demonstration period, based on Southwest Gas natural gas energy tariffs and the SRP small power plant buy back plan in early 2005.

May to October 2005 – summer rates (electric - \$0.0814/kWh, gas - \$0.81559/Therm)

November 2005 to April 2006 – winter rates (electric - \$0.0640/kWh, gas - \$0.81559/Therm)

	IdaTech nGen5	Plug Power Gensys
Output at 90% Availability	15,728 kWh	19,710 kWh
Production -- SAVINGS	\$1,145	\$1,434
Manufacturer reported efficiency	25%	26%
Input at 90% Availability	2,152 Therms	2,586 Therms
Consumption -- COST	\$1,755	\$2,109
Overall SAVINGS	-\$610	-\$675

Table 8-1: Estimated annual net energy savings of the two fuel cell systems at start of project.

8.5 Interconnection agreement

The installation and running of the two systems at the Army Reserve Center were a long time in coming after the project was accepted by CERL. Specifically, there were legal issues regarding liability between Arizona State University and Salt River Project, the local electrical utility. ASU-PTL originally planned to have both systems installed and running by December 2004. However, because of a delayed electrical interconnection agreement, the first system (Plug Power) was not commissioned until late March 2005.

8.7 Historical Utility Consumption

Project Duration Utility Consumption at the Herrera army reserve building									
	2005-2006		2003-2004		Usage Difference		Cost Difference		Total Monthly
Months	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Expenditure Difference
	kWh	Therm	kWh	Therm	kWh	Therm	\$	\$	\$
may	13320	597	27720	15	-14400	582	\$ (714.45)	\$ 436.50	\$ (277.95)
june	18480	475	39960	5	-21480	470	\$ (1,065.73)	\$ 352.50	\$ (713.23)
july	19440	512	42000	4	-22560	508	\$ (1,119.31)	\$ 381.00	\$ (738.31)
august	24120	573	49920	4	-25800	569	\$ (1,280.06)	\$ 426.75	\$ (853.31)
september	21600	666	48360	5	-26760	661	\$ (1,327.69)	\$ 495.75	\$ (831.94)
october	15840	669	41760	4	-25920	665	\$ (1,286.02)	\$ 498.75	\$ (787.27)
november	9240	710	31560	4	-22320	706	\$ (1,107.40)	\$ 529.50	\$ (577.90)
december	10800	371	26640	5	-15840	366	\$ (785.90)	\$ 274.50	\$ (511.40)
january	12000	280	24600	444	-12600	-164	\$ (625.15)	\$ (123.00)	\$ (748.15)
february	12120	721	24360	359	-12240	362	\$ (607.29)	\$ 271.50	\$ (335.79)
March	10080	782	28320	158	-18240	624	\$ (904.98)	\$ 468.00	\$ (436.98)
April	11280	571	31920	4	-20640	567	\$ (1,024.05)	\$ 425.25	\$ (598.80)
note: Water consumption not calculated. () = credit balance									
Total Yearly Expenditure								\$	(7,411.03)

Table 8-2: Historical Utility Consumption.

9.0 Electrical System

The Plug Power Gensys 5C and the IdaTech nGen5 required different electrical configurations. The Gensys delivers 120 Vac, 60Hz single-phase to the local grid. The nGen5 system is set to deliver 240 Vac, 60 Hz single-phase. In order to support each configuration, ASU-PTL ran 3-phase, 208 Vac, 50A service from the local grid transfer disconnect and distribution switch board. A one-line electrical diagram is shown in Figure 9-1.

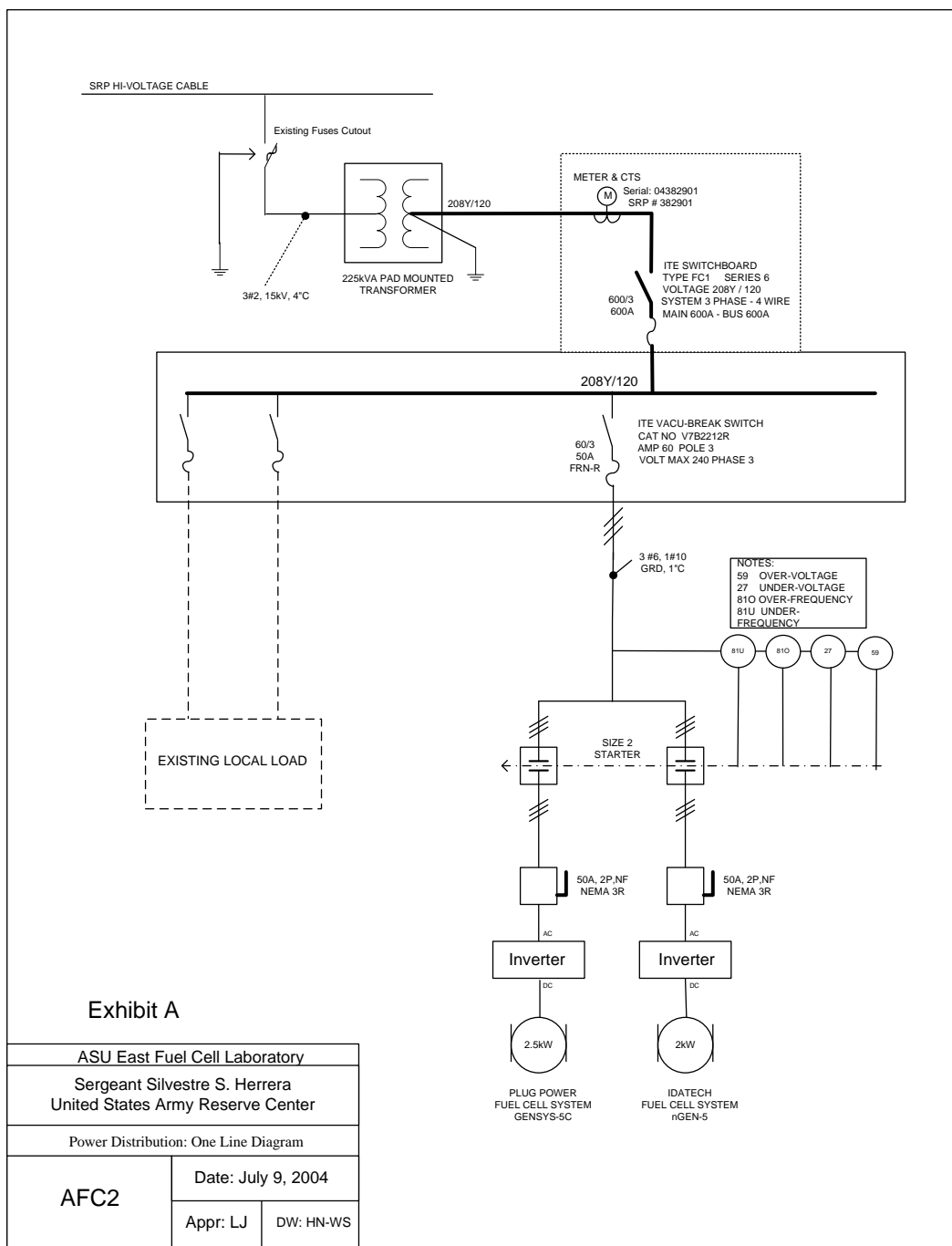


Figure 9-1: Fuel cell site electrical one-line diagram.

Both systems were connected only to the local electrical grid. No subsequent critical loads were connected. The systems were set to operate independently of one another, and in parallel to the grid. No loads inside the Reserve Center building would be affected by the operation of the fuel cell systems.

The IdaTech system requires a continuous grid-presence to operate. If the local grid goes off-line, the IdaTech system must be restarted manually (locally) or remotely by IdaTech engineers. The Plug Power system has a 48 Vdc battery, which can serve as a load temporarily, so the fuel cell stack can continue to supply low current DC power until the electric grid comes back on-line. The Plug Power inverter continues to survey the electric grid until it sees a 5-minute, uninterrupted, clean grid signal. The battery is also used to provide initial startup power until all stages of the system reformer reach operating temperatures. The inverters for both systems are UL1741 Listed for safety.

For redundancy, the local electric utility – Salt River Project – required additional grid voltage and frequency protection. ASU-PTL installed a solenoid, which was tripped by either a grid under/over voltage or under/over frequency protection relay.

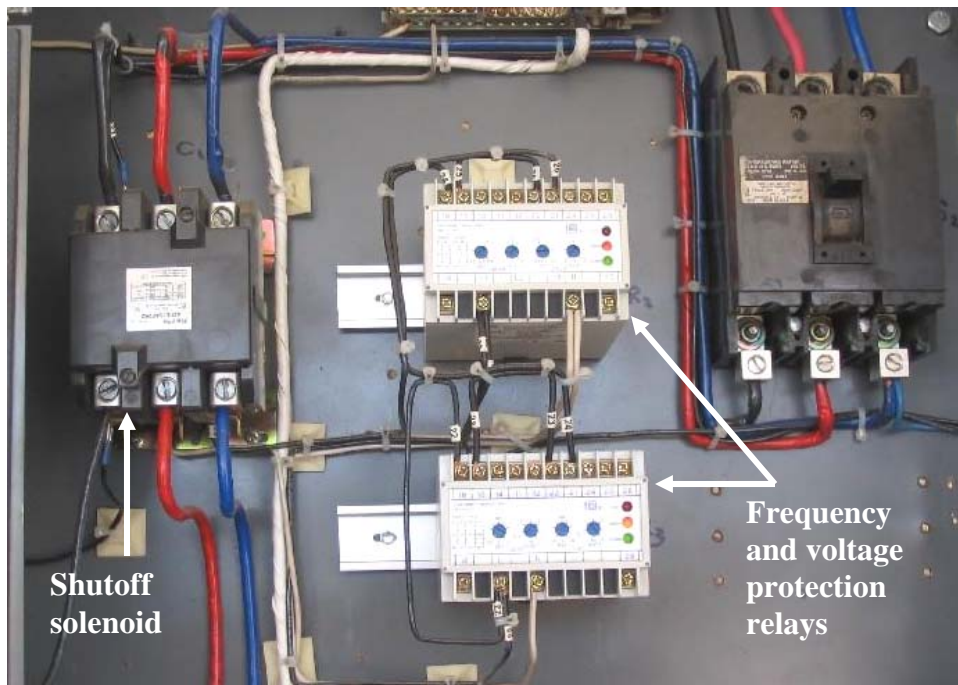


Figure 9-2: Additional grid protection as required by the local electric utility.

There are three physical disconnects external to each system, disregarding the voltage and frequency protection contact relay. The main utility disconnect (50A, fused) is located inside the Army Reserve building utility room. The second disconnect (50A, fused) is located just outside the fence line of the demonstration units. Each system has a third disconnect on its own platform.

10.0 Thermal Recovery System

Not used during this demonstration.

11.0 Data Acquisition System

11.1 Data Acquisition

The following parameters were measured and submitted in a monthly report:

- Ambient temperature
- Natural gas consumption
- Electrical energy supplied to grid
- Other temperatures/parameters deemed appropriate

Each of the above parameters was set to be measured externally to each fuel cell system. In this way, ASU-PTL took a “black box” approach in observing each of the systems. Each system used natural gas as an input fuel, and produced AC grid electricity to the local electric grid. Based on the “black box” approach, it does not matter to ASU-PTL what happens in between – within the processes of the system. The only concerns for the consumer are the total energy consumed by the system versus total energy produced, regardless of manufacturer claims or reports.

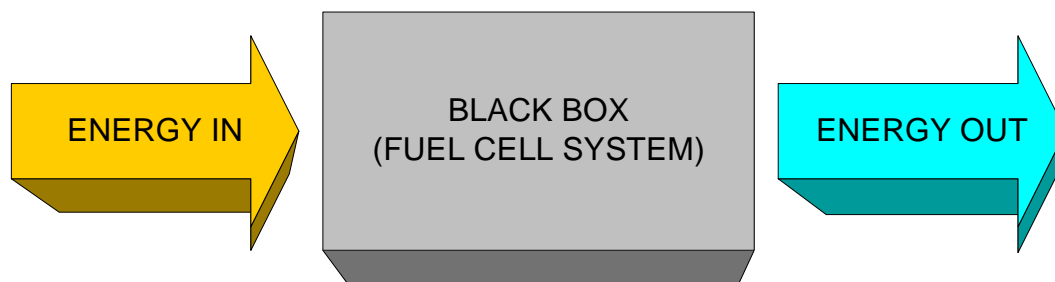


Figure 11-1: The “black box” approach for monitoring energy consumption and production.

In addition to the external system measurements, each manufacturer should supply its own internal system data. The Plug Power internal data was collected locally by ASU-PTL, while the IdaTech internal data was collected remotely by IdaTech engineers.

11.2 DAS system and set-up

The ASU-PTL external data was set up for collection in ten-minute intervals using two Campbell Scientific CR10X data acquisition systems – one for each system. ASU-PTL personnel chose the CR10X because of its durability and reliability, as well as a familiarity with the system.

The Plug Power CR10X was connected to the laptop via a Campbell Scientific NL100 Ethernet adapter. The IdaTech CR10X was connected through a 900MHz radio transmitter/receiver (an RF400) specifically designed for CR10X use in remote areas. The CR10X can connect to the NL100 through the RF400, allowing its data to be downloaded to the laptop. PC208W software, also from Campbell Scientific, was set up to retrieve the data at a local PC, where it will be stored in .CSV files and translated to an Excel spreadsheet.

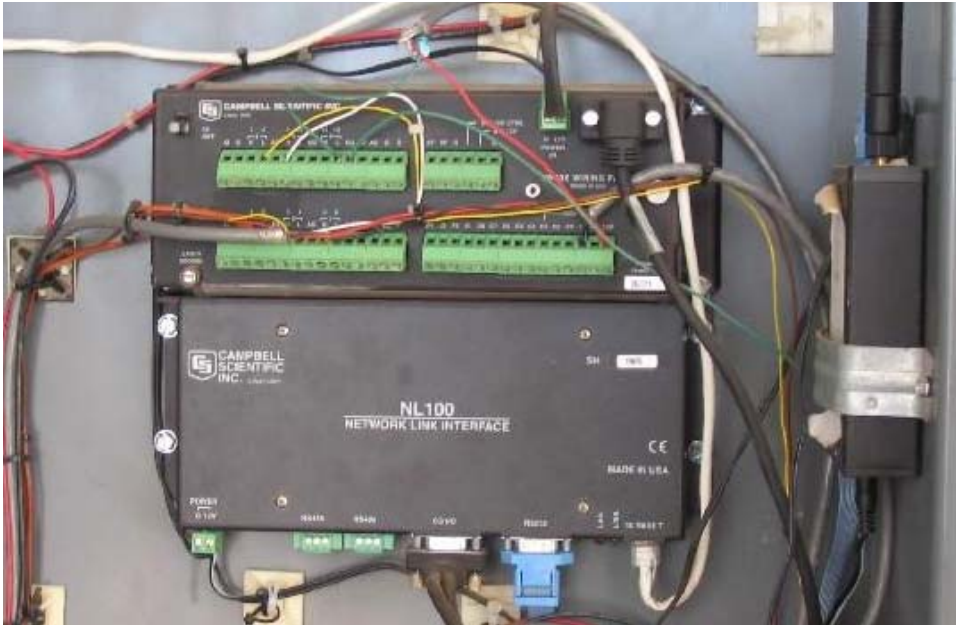


Figure 11-2: The ASU-PTL data acquisition system.

The Plug Power Gensys system has an onboard computer that can collect data every minute when hooked up through a direct line to a PC, through an RS232 cable. The IdaTech unit was hooked directly to the Internet through a satellite communication link provided by IdaTech. A diagram of the data acquisition layout is shown in the Appendix.

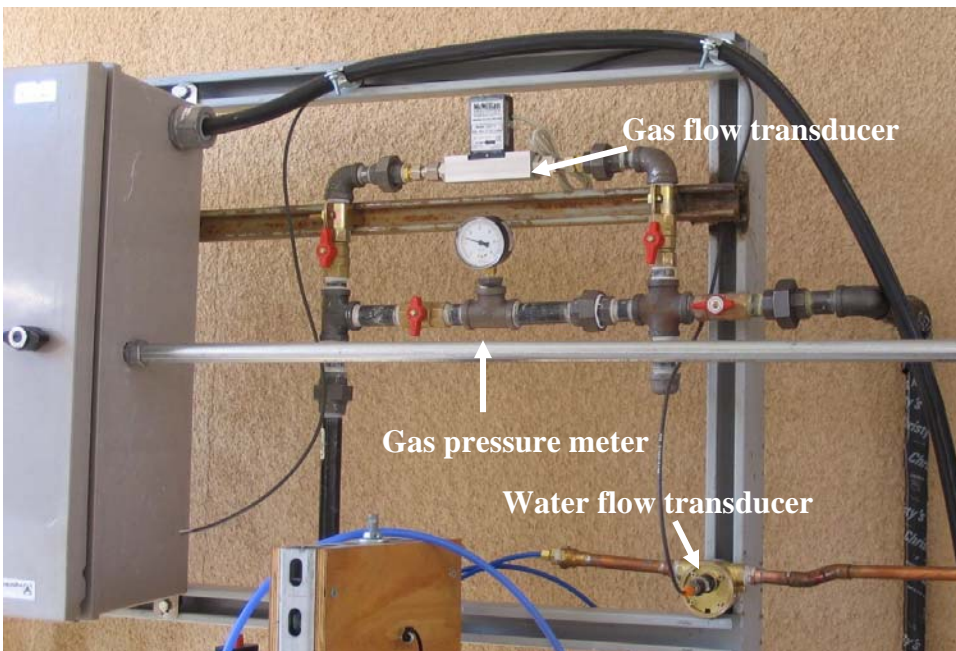


Figure 11-3: Monitoring system consumption.



Figure 11-4: AC power transducer used to measure the Plug Power Gensys. A similar model was used for IdaTech.

The entire ASU-PTL data acquisition system was powered by a battery, which was charged with a photovoltaic module. Because of this, the DAS remained independent of the electric grid and fuel cell systems. Data could continue to be collected whether or not the fuel cell systems were on-line or the grid was functional.

11.3 DAS system issues

Initially, the lab tried to set up a remote data connection, using an ISDN line for Internet service. Because of trouble with telephone communication on the campus and university firewalls, ASU-PTL decided to collect its data locally with an on-site laptop computer.

A particular data collection problem encountered in the beginning was the external monitoring of natural gas flow. The initial gas flow meter was a unit from Omega. It had problems accurately measuring gas flow when the pipes leading to the fuel cells would get heated by the sun. Much effort was put into searching for an acceptable meter that could cope with the temperature fluctuations in the gas pipe. However, nothing was found to meet this requirement. Finding a gas flow meter acceptable for this application will need to be found if another project of this scope is to be performed in the future.

12.0 Fuel Supply System

There are three input fuels in each gas-reforming fuel cell system:

- 1) natural gas;
- 2) water; and
- 3) air.

Oxygen is needed on the cathode side of a PEM fuel cell stack. The easiest way to get oxygen to the stack is by blowing ambient air across it. Because air is a free and readily available in any environment, its consumption was not measured in this investigation.

Hydrogen is needed for the anode side of a PEM fuel cell. For each system, natural gas and de-ionized water were needed for the combustion process inside a high-temperature reformer. In a typical steam reformer, temperatures of over 700°C are reached to enable the methane portion

of natural gas to be “cracked” into hydrogen (H_2) and carbon monoxide (CO). Because carbon monoxide is a poison to a PEM fuel cell, it must be reconverted into carbon dioxide (CO_2), which can pass harmlessly by the stack and out through the system exhaust. More stages are added to a steam reformer to minimize the amounts of CO that reach the stack. Also, the vast quantity of sulfur in natural gas is separated prior to combustion through filtration in desulphurization beds.

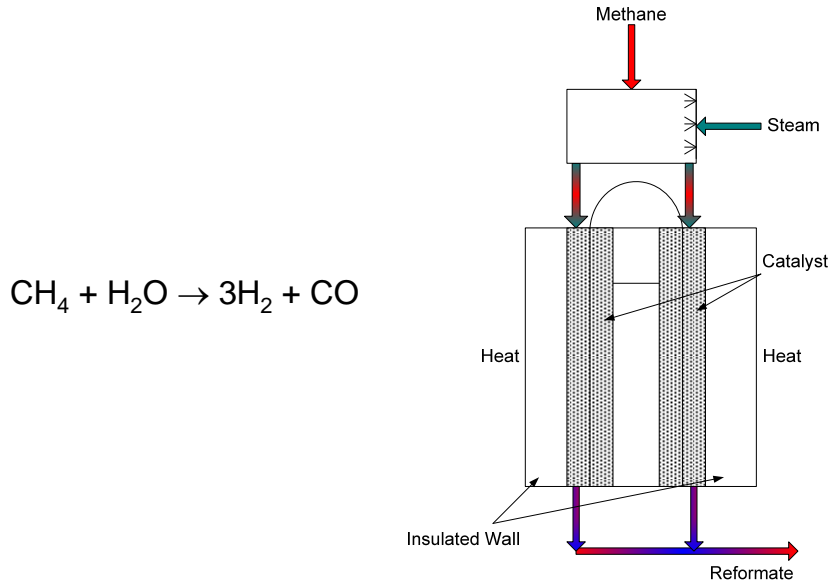


Figure 12-1: Drawing of a typical steam reformer, used to “crack” methane into hydrogen and carbon monoxide. The hydrogen can be used for a PEM fuel cell stack. The carbon monoxide must be mitigated in later reformer stages.

A water softener was installed to treat both systems’ incoming city water. Each system employed a reverse osmosis and deionization treatment plant. A picture of the water softener and Plug Power water treatment plant is shown in Figure 12-2, and a water line diagram is shown in Figure 12-3.

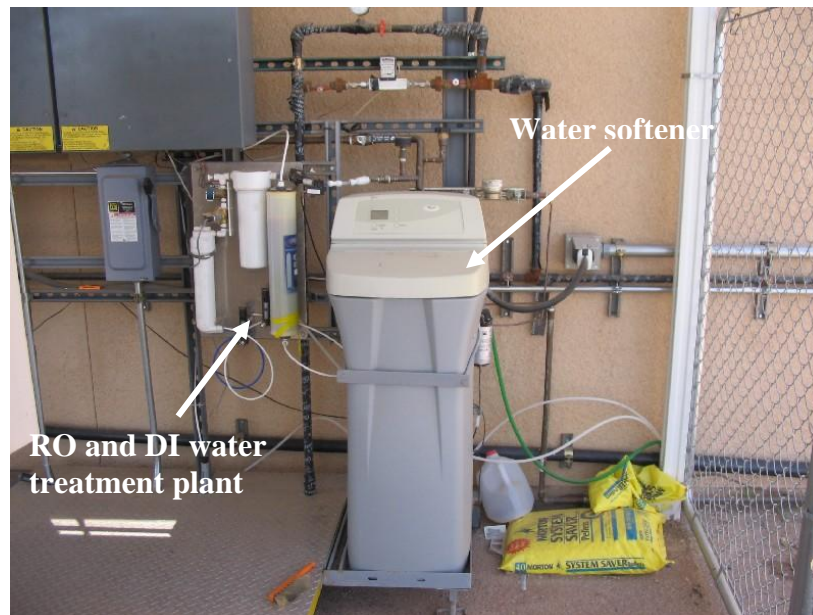


Figure 12-2: Water softener and Plug Power water treatment plant.

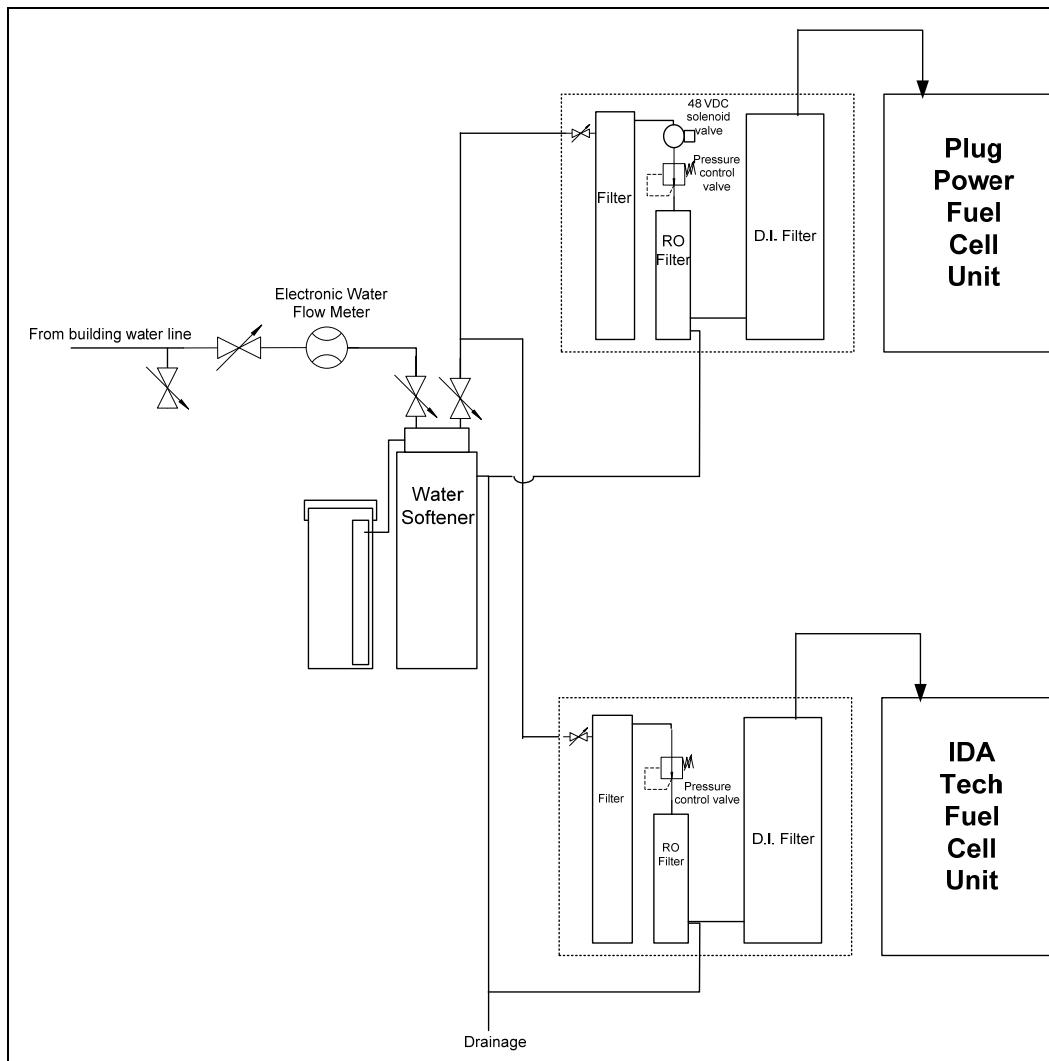


Figure 12-3: A diagram of the water line.

A natural gas line was tapped off of the existing $\frac{3}{4}$ " line at the building. A tee was made inside the boiler room, just before the boiler. The local gas pressure was measured consistently at 7 inches water-column (about 0.25 psig). A minimum of 4 INWC was needed to satisfy both systems' site requirements. A gas line diagram is shown in Figure 12-4.

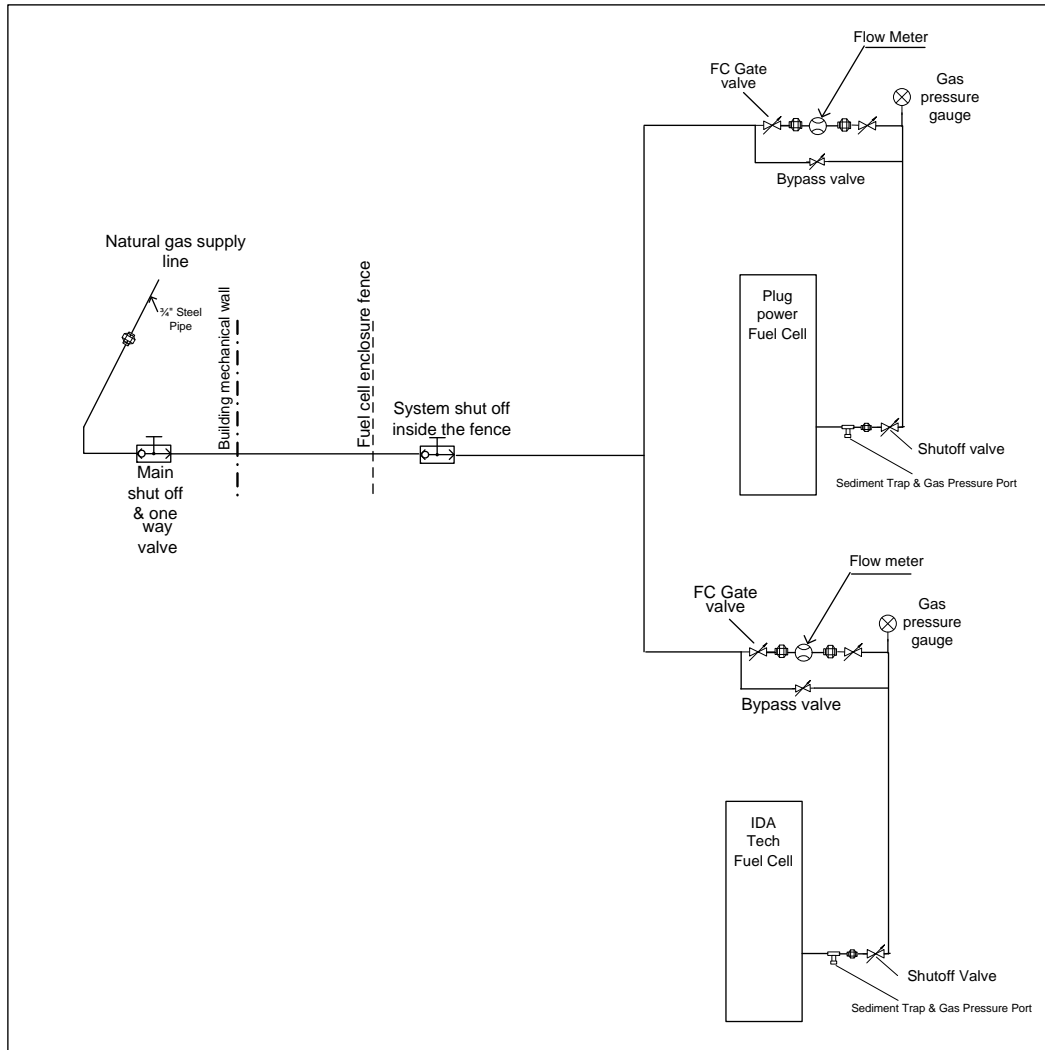


Figure 12-4: A diagram of the natural gas line.

A particular challenge that arose in the gas supply occurred in the winter months when the building's gas feed boiler was turned on. The IDATech unit required gas pressure above 5 INWC or it would shut itself down, contrary to the operational gas pressure rating of 4 INWC. When the boiler turned on, it consumed enough gas to drop the overall pressure of the pipeline causing the fuel cell shut down. No adjustments were made due to the scale of work it would have taken to correct this problem. The IDATech system was restarted remotely within 24 hours or less of shutdown and the problem only persisted for a period of 2 weekends when the building was being occupied.

13.0 Program Costs

System Capital Costs

Plug Power Gensys 5	\$70,000 USD
IDATech	\$133,115 USD

Table 13-1: Capital cost of fuel cell systems.

13.1 Installation Costs

The fuel cell site preparation and construction was prepared to handle two systems. An awning was constructed by an outside contractor, but everything else was handled by ASU-PTL, including electric, water, and natural gas lines. A platform was constructed for each fuel cell system. Each platform has a box for data collection. The Plug Power fuel cell platform also held electrical connection points and grid protection equipment. A list of the site construction costs is shown in Table 13-1.

Item	Company	Total Amount	Comments
Fuel Cell	IDA Tech	\$133,115.00	
Fuel cell	Plug Power	\$70,000.00	
square steel tubings	Davis Salvage	\$810.75	Platform
Maricopa County Air Quality Permit	Maricopa County	\$350.00	Site
Diamond plate (3ea) Steel 4x4x20'	Davis Salvage Inc.	\$994.52	Platform
Primer and Paint	Grainger	\$64.70	Platform
welding wire and 5/16" SS machine screw	Lowe's	\$143.58	Platform
Cutting wheel	Grainger	\$23.19	Platform
Platform	Grainger	\$188.03	Platform
Electrical	Basler Electric	\$400.00	Electrical
Electrical	Electric Supply Inc.	\$1,140.09	Electrical
Electrical	Electric Supply Inc.	\$97.58	Electrical
Electrical	Electric Supply Inc.	\$21.98	Electrical
Safety Equipment	K&P Sales Engineers	\$853.22	Data Acquisition
O/U voltage & frequency relays	Capital Enterprises INC.	\$485.10	Electrical
Electrical materials	Arizona Shade	\$1,567.48	Site
Electrical materials	Grainger	\$319.20	Site
Electrical materials	Electric Supply Inc.	\$517.89	Electrical
Water flow meter	Lowe's	\$482.83	Site
Water piping and fitting	Lowe's	\$91.91	Site
Water line accessories	Grainger	\$28.22	Site
Water line accessories	Grainger	\$13.37	Site
Gas Flow Sensor	R.D. McMillan Company, INC.	\$1,450.00	Data Acquisition
Watt meter	Davidge Controls	\$608.00	Data Acquisition
QWEST ISDN Hookup and 1st Month	QWEST	\$229.72	Data Acquisition
electrical control wiring system	Lowe's	\$32.39	Electrical
Fence surrounding the awning	Lowe's	\$407.87	Site
Fence surrounding the awning	Lowe's	\$26.67	Site
Static IP addresses for Internet	QWEST	\$433.71	Data Acquisition
Fluid devices	Grainger	\$133.25	Site
Piping and Fitting	Lowe's	\$123.31	Data Acquisition
Lantronix UDS200 - Ethernet adapter	GridConnect	\$249.00	Data Acquisition
Gas piping and fitting	Lowe's	\$72.17	Site
#10-24 x 2" and #8-32 x 2" machine	Lowe's	\$1.68	Site
Gas line connection for Army FC	CPM	\$670.00	Site
Class RK5 & K5, 60A fuses	Grainger	\$34.75	Electrical
Power cord strain relief, & terminal block	Grainger	\$14.80	Electrical
Lugs for #6 wire	Lowe's	\$7.80	Electrical
ISDN charges	AT&T	\$18.42	Data Acquisition
1 - 1/2" drain plug	Lowe's	\$1.48	Platform
Conduit connectors	Grainger	\$35.53	Electrical
Dec Ip charges	Qwest	\$146.03	Data Acquisition
Webcam for Army Fuel Cell project	Fry's Electronics	\$339.96	Data Acquisition
200' 4-conductor cable	Mouser	\$85.35	Electrical
Dec LD charges	AT&T	\$18.42	Data Acquisition
Jan charges	Qwest	\$148.33	Data Acquisition
Jan LD charges	AT & T	\$18.72	Data Acquisition
IP address charges	Qwest	\$148.36	Data Acquisition
Salt Tablets	Lowes	\$17.20	Site
Feb IP LD charges	AT & T	\$18.78	Data Acquisition
Power transducers	Jim Gray & Associates	\$520.00	Data Acquisition
Brass & copper fittings + tube cutter	McMaster-Carr	\$54.00	Site
Water Booster Pump	Spectrapure	\$262.50	Site
2 water meters	Omega Engineering	\$368.00	Data Acquisition
Brass fittings	McMaster-Carr	\$25.88	Site
IdaTech - Start up training and service	IdaTech	\$3,475	Training
UPS delivery - Omega Engineering	UPS	\$41.61	Data Acquisition
Water flow rotameters	McMaster-Carr	\$78.78	Data Acquisition
Water flow rotameter	McMaster-Carr	\$39.39	Data Acquisition
UPS shipment	UPS	\$44.24	Data Acquisition
Gas meter maintenance	McMillan Company	\$150.00	Data Acquisition
Natural gas flow meters	Alicat Scientific	\$1,800.00	Data Acquisition
Stainless steel tube fittings	McMaster-Carr	\$97.81	Site
repair meter	McMillan Company	\$150.00	Data Acquisition
charge controller	ETA engineering	\$135.15	Data Acquisition
		\$224,443	

Table 13-2: Fuel cell site equipment costs.

Performance Monitoring	Maintenance	Management/Salaries	Decommissioning
\$8,026	\$16,059	\$81,460	\$0

Table 13-3: Performance Monitoring, Maintenance, Management, and Decommissioning costs

14.0 Milestones/Improvements

IDATech

During the summer months it was found that the IDATech system was experiencing cooling problems. The radiator fan – a standard DC radiator fan for a commercial passenger vehicle – was not intended for continuous use and was unable to sufficiently cool the system. The consequence was a series of shut downs to replace burnt out motors and a burnt wire and relay. As a result, IDATech redesigned the cooling system to include an AC operated fan with greater cubic feet per minute (CFM). The new fan was mounted on the outside of the structure due to its size. The new fan corrected the issue; the cooling system from that point did not experience any failures.



Figure 14-1: New fan placement on IDATech system

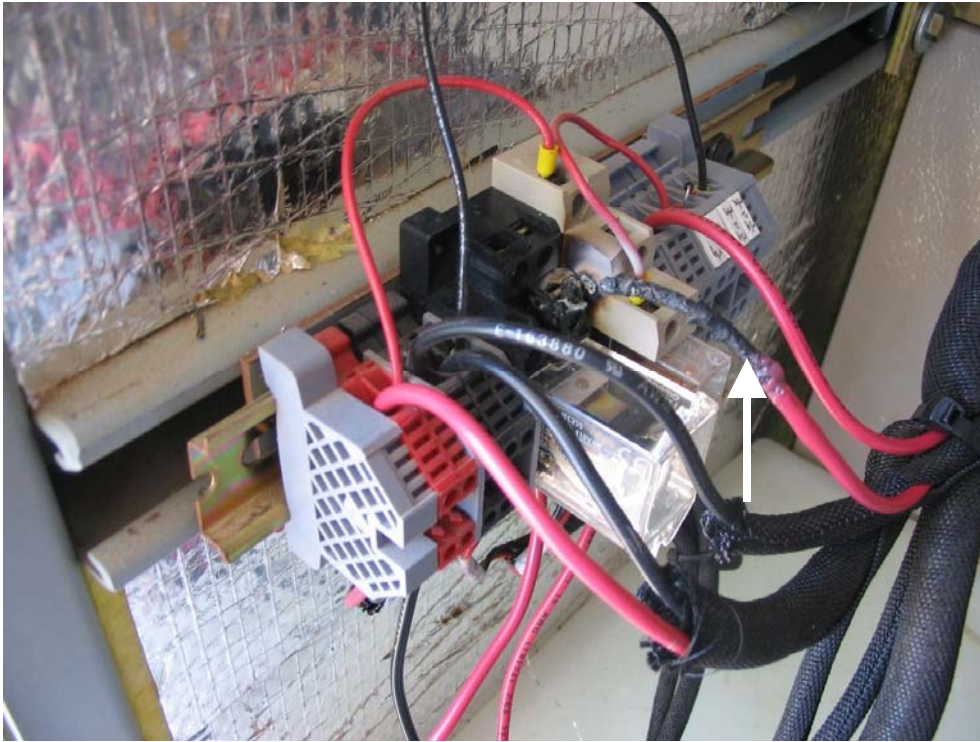


Figure 14-2: Burnt relay and wire from over current.

15.0 Decommissioning/Removal/Site Restoration

The fuel cells were decommissioned and shut off at different times, based on operational objectives. IDATEch completed its service on May 23, 2006 and Plug Power completed its service on June 30, 2006. The tear down of the site took place on January 16, 2006. The fuel cells were taken back to the ASU-PTL site for storage.

The Army Reserve building is currently being used in limited capacity and its future use is not known; therefore, complete restoration of the site was unneeded. The tear down process began with first detaching the main peripherals from the fuel cell stands, namely the water, gas, data and electric components. Figures 15-1 through 15-4 show the disconnection points. The awning and peripheral piping for gas and water were left attached to the building. Figure 15-5 shows the site after the fuel cells were removed.



Figure 15-1: Gas disconnect point.



Figure 15-3: Electric disconnect point.



Figure 15-2: Water disconnect point.

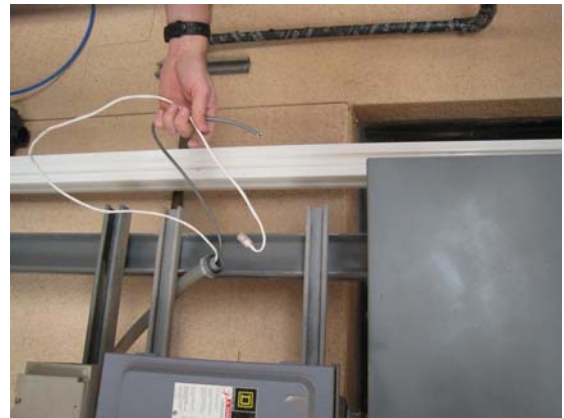


Figure 15-4: Data disconnect point.



Figure 15-5: Site after final clean up and restoration. The awning was left at the request of the U.S. Army Reserve.

16.0 Additional Research/Analysis

No additional research.

17.0 Conclusions/Summary

In this demonstration, fuel cell systems from two manufacturers were operated side-by-side in a shared environment. Over the course of the evaluation, each system experienced periods of down time and strong operational runs. The chart in Figure 17-1 shows the accumulated run time total of each system over time. Figure 17-2 shows the simple availability of each system during each month of the demonstration period.

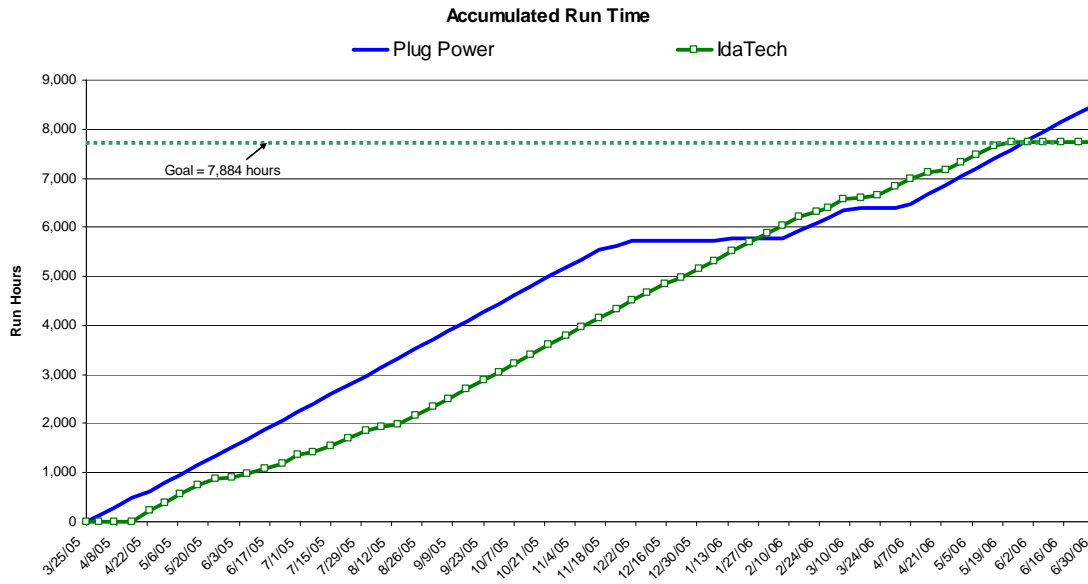


Figure 17-1: Accumulated run time total of each system.

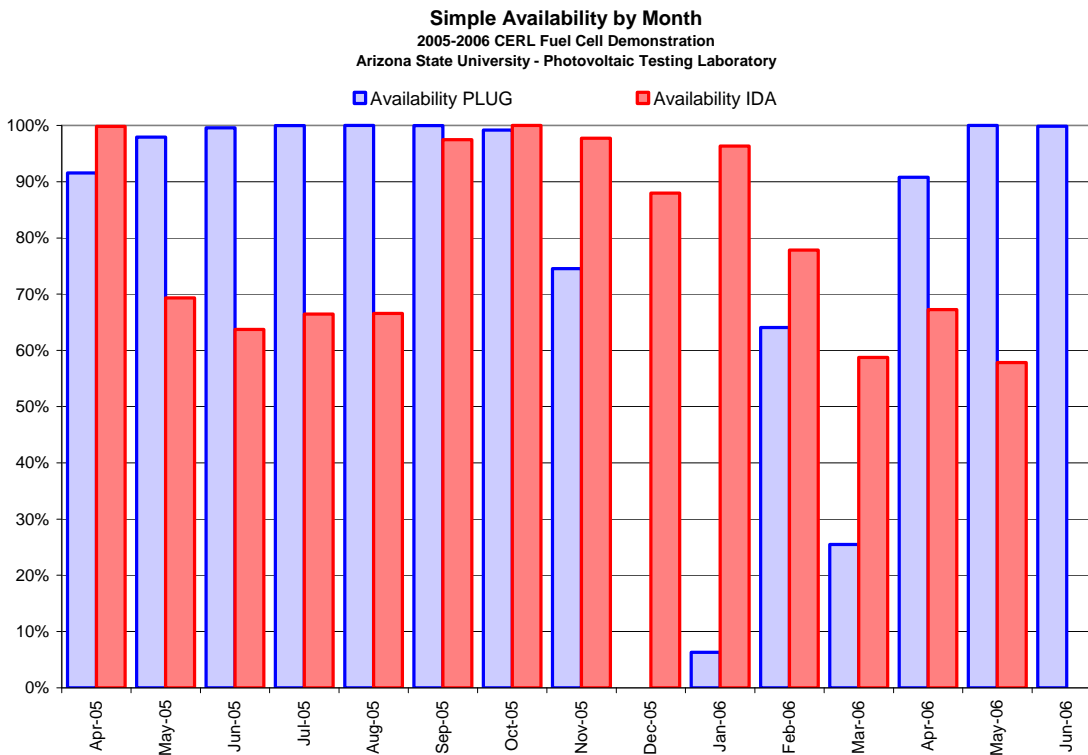


Figure 17-2: Simple availability of each fuel cell system by month.

Between the period of March 2005 and July 2006, over 33 MWh of ac electrical energy have been delivered to the grid from the two systems. The IdaTech system delivered 14.5 MWh, with a simple availability of 78%. The Plug Power system delivered just over 19 MWh, with a simple availability of 75%. Each system was run at about half its power capacity, to ensure a longer fuel cell stack life, based on previous experience.

The overall electrical efficiency of each system was between 20% and 22%, based on the lower heat value of the input fuel (natural gas) and the AC electrical energy output of the systems. Thermal efficiency was not calculated, because no thermal energy was recovered. By using the thermal heat recovery offered in both CHP (combined heat & power) systems, an efficiency of nearly 40% might be realistically expected.

Down times were most often related to the system reformers and auxiliary subsystems, and not to the PEM fuel cell stacks. The fuel cell stacks rely on consistent, clean input fuel (hydrogen) and steady operational temperatures (between 50°C and 65°C).

Plug Power's system was strong for the first seven months of operation, and then experienced catastrophic failures due to multiple reformer issues. The lab had difficulty determining the cause of the failures, with more than one cause relaying the same symptom. Once the causes were addressed, the Plug Power system again ran strong until the end of the demonstration period.

The IdaTech system had chronic problems due to system cooling in the first half of the evaluation. The second half of the evaluation had issues related mainly to reformer and stack problems. The system seemed to run best during the winter months – a mild climate period in the Arizona desert.

Natural gas was likely chosen as an input fuel because of its availability in the existing U.S. infrastructure. However, the cracking of natural gas through steam reformers introduces the issue of carbon monoxide poisoning on the low-temperature PEM fuel cell membranes, and inevitable stack deterioration. And, as was observed throughout this demonstration, the complexity of the systems proved to be a hurdle to each system's availability.

	Plug Power Gensys 5C	IdaTech nGen5
Demonstration Period	10,380 hours	9.893 hours
Run Hours	7,782 hours	7,748 hours
Simple Availability	75%	78%
AC Electrical Energy Production	19,048 kWh	14,550 kWh
Energy Consumption of Natural Gas	302 Therms	248 Therms
Electrical Efficiency	21.55%	20.0%
Unplanned Outages	26	45

Table 17-1: Basic operational summary of the two fuel cell systems.

Appendix

Monthly Performance Data

Format for PEM Fuel Cell Performance Data

System Number: <div>GenSys 5C - B285</div>				Commission Date: <div>3/25/2005</div>				Site Location(City/State): <div>Mesa, AZ</div>										
Site Name: <div>Sylvestre S. Herrera</div>				Fuel Cell Type: <div>PEM</div>														
Fuel Type: <div>Natural Gas</div>				Maintenance Contract: <div>ASU-PTL</div>														
Low Heating Value: <div>1,027 Btu/cu ft</div>				Local Residential Fuel: <div>1.00787</div>				\$/Therm <div>0.78876</div>										
Capacity kW <div>5</div>				Local Residential Elec: <div>0.0907</div>				\$/Therm <div>0.0423</div>										
Month	Run Time (Hours)	Time in Period (Hours)	Availability (%)	Energy Produced (kWe-hrs AC)	Output Setting (kW)	Average Output (kW)	Capacity Factor (%)	Fuel Usage, LHV (BTUs)	Fuel Usage (SCF)	Electrical Efficiency (%)	Thermal Heat Recovery (BTUs)	Heat Recovery Rate (BTUs/hour)	Thermal Efficiency (%)	Overall Efficiency (%)	Number of Scheduled Outages	Scheduled Outage Hours	Number of Unscheduled Outages	Unscheduled Outage Hours
<i>insert month</i>	<i>insert operating hours</i>	<i>insert hours in month</i>	*1	<i>insert produced energy</i>	<i>insert output setting</i>	*2	*3	<i>insert fuel consumption</i>	<i>insert fuel consumption</i>	*4	<i>insert heat recovery</i>	*5	*6	*7	<i>insert value</i>	<i>insert value</i>	<i>insert value</i>	<i>insert value</i>
March-05	130	156	83%	325	2.5	2.51	41.69%	4.45E+06	4.336	24.93%	0	0	0.00%	24.93%	0	0	1	26.25
April-05	659	720	92%	1,643	2.5	2.49	45.65%	2.21E+07	21.738	25.40%	0	0	0.00%	25.40%	0	0	1	60.737
May-05	729	744	98%	1,815	2.5	2.49	48.79%	2.80E+07	27.280	22.12%	0	0	0.00%	22.12%	0	0	4	15.4
June-05	717	720	100%	1,808	2.5	2.52	50.22%	2.89E+07	28.175	21.33%	0	0	0.00%	21.33%	0	0	7	3.1
July-05	744	744	100%	1,876	2.5	2.52	50.43%	2.79E+07	27.047	23.06%	0	0	0.00%	23.06%	0	0	2	0.2
August-05	744	744	100%	1,893	2.5	2.54	50.89%	3.02E+07	29.359	21.43%	0	0	0.00%	21.43%	0	0	0	0
September-05	720	720	100%	1,830	2.5	2.54	50.93%	2.96E+07	28.802	21.12%	0	0	0.00%	21.12%	0	0	1	0.2
October-05	738	744	98%	1,873	2.5	2.54	50.35%	3.29E+07	32.044	19.43%	0	0	0.00%	19.43%	1	6.2	0	0
November-05	537	720	75%	1,357	2.5	2.53	37.68%	2.25E+07	21.913	20.59%	0	0	0.00%	20.59%	0	0	4	183.3
December-05	0	744	0%	0	0	0.00	0.00%	0.00E+00	0	0.00%	0	0	0.00%	0.00%	0	0	1	744
January-06	47	744	6%	67	2.5	1.43	1.81%	1.48E+06	1.446	15.50%	0	0	0.00%	15.50%	0	0	1	697
February-06	431	672	64%	724	2.5	1.68	21.95%	1.36E+07	13.248	18.17%	0	0	0.00%	18.17%	0	0	1	241.4
March-06	190	744	25%	309	2.5	1.63	8.31%	5.99E+06	5.800	17.62%	0	0	0.00%	17.62%	0	0	2	554.5
April-06	654	720	91%	1,860	2.5	2.54	46.11%	2.40E+07	23.331	23.65%	0	0	0.00%	23.65%	0	0	1	66.4
May-06	744	744	100%	1,867	2.5	2.51	50.19%	3.03E+07	29.459	21.07%	0	0	0.00%	21.07%	0	0	0	0
June-06	708	709	100%	1,714	2.5	2.42	48.36%	2.68E+07	26.131	21.80%	0	0	0.00%	21.80%	0	0	0	0.1
Running Totals																		
	Total Run Time	Total Hours in Period	Total Availability (%)	Total Energy Produced	Average Output Setting	Total Average Output	Total Capacity Factor (%)	Total Fuel Usage	Total Fuel Usage	Average Electrical Efficiency (%)	Total Thermal Heat Recovery	Average Heat Recovery Rate (*)	Average Thermal Efficiency (%)	Average Overall Efficiency (%)	Total Outages	Total Hours	Total Outages	Total Hours
	7,782	10,380	75%	19,048	2.50	2.45	36.70%	3.02E+08	294,008	21.55%	0	0	0.00%	21.55%	1	6.2	26	2592.5

Format for PEM Fuel Cell Performance Data

System Number: nGen5 - 0083E				Commission Date: 4/14/2005				Site Location(City/State): Mesa, AZ									
Site Name: Sylvestre S. Herrera				Fuel Cell Type: PEM													
Fuel Type: Natural Gas				Maintenance Contract: ASU-PTL													
Low Heating Value: 1,027 Btu/cu ft				Local Residential Fuel: 1.00787				\$/Therm Base Fuel Cost per TI 0.78876									
Capacity kW 4.5				Local Residential Elec: 0.0907				\$/Therm Local Base Electricity 0.0423									
Month	Run Time (Hours)	Time in Period (Hours)	Availability (%)	Energy Produced (kWe-hrs AC)	Output Setting (kW)	Average Output (kW)	Capacity Factor (%)	Fuel Usage, LHV (BTUs)	Electrical Efficiency (%)	Thermal Heat Recovery (BTUs)	Heat Recovery Rate (BTUs/hour)	Thermal Efficiency (%)	Overall Efficiency (%)	Number of Scheduled Outages	Scheduled Outage Hours	Number of Unscheduled Outages	Unscheduled Outage Hours
insert month	insert operating hours	insert hours in month	*1	insert produced energy	insert output setting	*2	*3	insert fuel consumption	*4	insert heat recovery	*5	*6	*7	insert value	insert value	insert value	insert value
April-05	388.2	388.9	100%	769.68	2	1.98	38.53%	1,11E+07	10819	23.62%	0	0.00%	23.62%	1	0.7	0	0
May-05	515.9	744	69%	1023.31	2	1.98	27.51%	1,45E+07	14124	24.09%	0	0.00%	24.09%	0	0	3	228.1
June-05	458.7	720	64%	823.66	2.3	1.80	22.88%	1,08E+07	10550	23.59%	0	0.00%	23.59%	0	0	6	261.3
July-05	484.4	744	66%	963.57	2.3	1.95	25.90%	1,13E+07	11028	23.04%	0	0.00%	23.04%	1	1.1	6	248.5
August-05	485.2	744	67%	970.57	2	1.96	26.09%	1,27E+07	12233	26.18%	0	0.00%	26.18%	0	0	7	248.8
September-05	701.9	720	97%	1370.6	2	1.95	38.07%	1,98E+07	19284	23.63%	0	0.00%	23.63%	0	0	2	18.1
October-05	744	744	100%	1390.33	2	1.87	37.37%	2,38E+07	23012	20.08%	0	0.00%	20.08%	0	0	0	0
November-05	703.8	720	98%	1262.17	2	1.79	35.06%	2,49E+07	24206	17.33%	0	0.00%	17.33%	1	16.2	1	16.2
December-05	654.5	744	88%	1157.36	2	1.77	31.11%	2,40E+07	23368	16.46%	0	0.00%	16.46%	1	73.7	2	15.8
January-06	716.6	744	96%	1353.3	2	1.89	36.38%	2,64E+07	25745	17.47%	0	0.00%	17.47%	1	1.5	3	25.9
February-06	522.9	672	78%	922.38	2	1.76	27.46%	1,93E+07	18797	16.31%	0	0.00%	16.31%	0	0	7	149.2
March-06	437.1	744	59%	789.92	2	1.81	21.23%	1,60E+07	15606	16.93%	0	0.00%	16.93%	0	0	1	306.9
April-06	484.2	720	67%	942.28	2	1.95	26.17%	1,83E+07	17932	17.56%	0	0.00%	17.56%	0	0	3	235.8
May-06	430.5	744	58%	812.33	2	1.89	21.84%	1,52E+07	14768	18.29%	0	0.00%	18.29%	1	7.5	4	306
Running Totals																	
	Total Run Time	Total Hours in Period	Total Availability (%)	Total Energy Produced	Average Output Setting	Total Average Output	Total Capacity Factor (%)	Total Fuel Usage	Average Electrical Efficiency (%)	Total Thermal Heat Recovery	Average Heat Recovery Rate	Average Thermal Efficiency (%)	Average Overall Efficiency (%)	Total Outages	Total Hours	Total Outages	Total Hours
	7,748	9,893	78%	14,550	2.04	1.88	29.42%	2,48E+08	241,462	20.03%	0	0.00%	20.03%	5	84.5	45	2060.6

Maintenance Logs/Events Log

Fuel Cell Events Log

Date	Time	System	Event/Comment	Event Code	Scheduled/Unscheduled	Hours Down
3/25/05	12:00	Plug Power	System initial startup.	START	SCH	0
3/30/05	12:39	Plug Power	Unscheduled outage. DI water solenoid fuse blown. Fuse F57 on the SARC board.	E	UNSCH	26.25
4/6/05	6:34	Plug Power	Unscheduled outage. DI water solenoid fuse blown. Fuse F57 on the SARC board.	E	UNSCH	1.367
4/14/05	19:00	IdaTech	System initial startup.	START	SCH	0
4/17/05	5:00	Plug Power	Unschedule outage. Bad relay (K3) to CPO heater (HR2).	E	UNSCH	60
4/19/05	17:00	Plug Power	System restarted and back up into steady state operation.	START	SCH	0
5/12/05		Plug Power	Installed Alicat Scientific gas meter	LAB	SCH	0
5/13/05		IdaTech	Installed Alicat Scientific gas meter	LAB	SCH	0
5/13/05	11:54	IdaTech	Unscheduled outage. Low gas pressure due to new meter.	LAB	UNSCH	0.5
5/20/05	9:24	Plug Power	Unscheduled outage. No clear cause.	UNKWN	UNSCH	4
5/21/05	15:00	IdaTech	Unscheduled outage. Flame burnout	REF	UNSCH	127.7
5/27/05	7:18	Plug Power	Unscheduled outage. Low Battery	BAT	UNSCH	10.3
5/27/05	20:06	IdaTech	Unscheduled outage. Flame burnout	REF	UNSCH	99.9
6/3/05	20:35	Both	Loss of grid	GRID	UNSCH	0.18
6/5/05	2:50	Plug Power	Loss of grid	GRID	UNSCH	0.1
6/5/05	3:00	IdaTech	Power down for reformer and stack replacement. Also replaced desulphurization bed and water filters.	FC	UNSCH	109.9
6/11/05	7:18	IdaTech	Loss of grid	GRID	UNSCH	51
6/11/05	7:18	Plug Power	Loss of grid	GRID	UNSCH	1.7
6/12/05	8:48	Plug Power	Loss of grid	UNKWN	UNSCH	0.3
6/14/05	21:48	Plug Power	Loss of grid	GRID	UNSCH	0.2
6/14/05	21:48	IdaTech	Loss of grid	GRID	UNSCH	13.2
6/20/05	22:30	IdaTech	Water - temperature problems	FC	UNSCH	35.1
6/22/05	10:36	IdaTech	Water flow meter clogged	H2O	UNSCH	37
6/23/05	20:48	Plug Power	Loss of grid	GRID	UNSCH	0.2
6/23/05	22:12	Plug Power	Loss of grid	GRID	UNSCH	0.4
7/2/05	13:12	IdaTech	Cogen cooling fan not running. Fan motor bad. Replaced.	BOP	UNSCH	119.6
7/11/05	10:18	IdaTech	Replaced coolant with distilled water.	BOP	SCH	1.1
7/11/05	17:06	IdaTech	Loss of grid	GRID	UNSCH	15.9
7/11/05	17:06	Plug Power	Loss of grid	GRID	UNSCH	0.1
7/12/05	16:00	IdaTech	Cogen/cabinet temperature too high	BOP	UNSCH	15.8
7/13/05	14:42	IdaTech	Cogen/cabinet temperature too high	BOP	UNSCH	16.7
7/17/05	14:54	IdaTech	Cogen/cabinet temperature too high	BOP	UNSCH	17.8
7/22/05	20:48	IdaTech	Loss of grid	GRID	UNSCH	60.9
7/22/05	20:48	Plug Power	Loss of grid	GRID	UNSCH	0.1
8/3/05	3:54	IdaTech	Cogen/cabinet temperature too high - fan motor relay contact wire burnt, replace fan motor, replaced desulphur bed	BOP	UNSCH	34.1
8/4/05	16:12	IdaTech	Low H2 Pressure indicated	FC	UNSCH	16.9
8/6/05	9:18	IdaTech	LC filter for radiator fan power loop was burnt. Sent back to IdaTech for repair and reinstalled. Replaced fan motor relay base	BOP	UNSCH	149.7
8/13/05	3:30	IdaTech	Problems with radiator fan circuit	BOP	UNSCH	9.3
8/15/05	6:30	IdaTech	Problems with radiator fan circuit	BOP	UNSCH	26.7
8/17/05	7:12	IdaTech	Radiator fan circuit troubleshooting	BOP	SCH	1.5
8/23/05	9:00	IdaTech	Changed radiator fan circuit from DC operation to AC, replaced fan motor relay	BOP	SCH	10.5
9/1/05	16:00	IdaTech	Loss of grid	GRID	UNSCH	17.5
9/20/05	5:06	IdaTech	Loss of grid	GRID	UNSCH	0.6
9/20/05	5:06	Plug Power	Loss of grid	GRID	UNSCH	0.2
10/28/05	13:30	Plug Power	12kWh maintenance, replaced snorkel filter, mass flow rate sensor, air intake filter, DI(charcol and RO filters), polishing filter and desulphur bed	MAINT	SCH	6.2
11/14/05		Plug Power	Humidifier level low.	REFORM	UNSCH	7.1
11/16/05		IdaTech	DI water level for reformer insufficient.	REFORM	UNSCH	16.2
11/19/05		Plug Power	Humidifier level low.	REFORM	UNSCH	104.5
11/23/05		Plug Power	Humidifier level low.	REFORM	UNSCH	3.2
11/28/05	3:30	Plug Power	Humidifier level low.	REFORM	UNSCH	1021
12/1/05		Plug Power	Continued problems with Humidifier level. Placed new level sensor in system, but problem persisted. Increased inlet water pressure, but problem persisted. Sent data to Plug Power Tech Support for review, but they could not find problem, either.	REFORM	UNSCH	0
12/6/05		IdaTech	System shutdown due to hydrogen recirculation pump.	FC	UNSCH	11.6
12/15/05		IdaTech	System shutdown due to hydrogen recirculation pump.	FC	UNSCH	4.2
12/14/05		Plug Power	ATO startup failure. ATO reactor heater was found to be open.	REFORM	UNSCH	0
12/16/05	10:18	IdaTech	Scheduled fuel cell stack replacement. Also, hydrogen recirculation pump was replaced. Stack was degrading.	FC	SCH	73.7
1/9/06	13:00	IdaTech	Replaced desulphurization bed.	MAINT	SCH	3
1/9/06	16:30	Plug Power	System back on-line after replacing ATO reactor can.	REFORM	SCH	0
1/11/06	15:00	Plug Power	System manually shut down to perform software upgrade. System remained down during restart attempt.	MAINT	UNSCH	696.6
1/17/06	3:54	IdaTech	Blown fuse on inverter.	BOP	UNSCH	13.7
1/20/06	13:36	IdaTech	Unknown	BOP	UNSCH	5.9
2/9/06	15:36	Plug Power	System back on-line after replacement of exhaust pipe and Humidifier level sensor.	REFORM	SCH	0
2/9/06	11:18	IdaTech	Low gas pressure.	REFORM	UNSCH	2.5
2/10/06	1:24	IdaTech	Low gas pressure.	REFORM	UNSCH	11.1
2/15/06	9:30	IdaTech	Hydrogen Leak due to hole in hose.	REFORM	UNSCH	28.4
2/18/06	4:18	Plug Power	FC contactor timeout.	BOP	UNSCH	59.5
2/18/06	20:30	IdaTech	Low gas pressure.	REFORM	UNSCH	38.8
2/21/06	6:06	IdaTech	Low gas pressure.	REFORM	UNSCH	5.1
2/22/06	5:06	IdaTech	Low gas pressure.	REFORM	UNSCH	5.8
2/23/06	6:00	IdaTech	Low gas pressure.	REFORM	UNSCH	5.2
3/9/06	18:00	IdaTech	Bad coolant pump	BOP	UNSCH	
4/3/06		Plug Power	Restarted Plug Power system after replacing the fuel cell stack.	FC	SCH	0
5/15/06	10:06	IdaTech	Replaced desulphurization bed.	REFORM	SCH	7.5
5/16/06	11:48	IdaTech	Reformer startup problems.	REFORM	UNSCH	3.8
5/17/06	11:54	IdaTech	Reformer startup problems.	REFORM	UNSCH	6
5/18/06	12:54	IdaTech	Reformer startup problems.	REFORM	UNSCH	93.8
5/23/06	13:36	IdaTech	Reformer startup problems.	REFORM	UNSCH	202.4
6/7/06	16:46	Plug Power	Local grid outage.	GRID	UNSCH	0.9
6/30/06	13:00	Plug Power	Final system shutdown. Manual shutdown. End of evaluation period.	STOP	SCH	

Weather data over the operational period

Weather conditions at Photovoltaic Testing Laboratory
US Army Corps of Engineers - CERL - Fuel Cell Demonstration
March 2005 to June 2006

Month	Temperature (F)			Temperature (C)			Humidity (%)			Precip (inches)
	High	Avg	Low	High	Avg	Low	High	Avg	Low	
Mar-05	72.5	60.4	48.1	22.5	15.8	8.9	79.4	56.8	27.1	0.05
Apr-05	84.0	68.6	53.2	28.9	20.3	11.8	52.4	30.9	11.7	0.23
May-05	93.9	78.8	63.8	34.4	26.0	17.7	43.1	26.5	11.1	0.00
Jun-05	102.0	86.7	71.4	38.9	30.4	21.9	36.6	23.2	9.3	0.35
Jul-05	107.7	94.0	80.4	42.1	34.4	26.9	44.4	29.5	13.4	0.08
Aug-05	100.9	89.8	78.8	38.3	32.1	26.0	67.4	46.5	23.8	0.24
Sep-05	99.4	85.5	71.5	37.5	29.7	21.9	52.5	30.8	14.1	0.00
Oct-05	88.6	75.5	62.4	31.5	24.2	16.9	61.3	41.0	19.4	0.13
Nov-05	78.6	63.4	48.1	25.9	17.5	8.9	47.1	30.9	14.4	0.00
Dec-05	69.3	54.4	39.5	20.7	12.4	4.2	53.1	35.6	17.0	0.00
Jan-06	70.0	55.0	40.0	21.1	12.8	4.4	44.7	28.9	14.0	0.00
Feb-06	74.5	58.9	43.1	23.6	14.9	6.2	42.4	27.2	12.3	0.00
Mar-06	71.9	60.4	48.8	22.2	15.8	9.3	67.1	45.7	20.7	0.50
Apr-06	83.4	69.4	55.4	28.5	20.8	13.0	49.2	30.0	13.2	0.00
May-06	96.7	81.3	66.0	35.9	27.4	18.9	32.4	20.2	8.3	0.00
Jun-06	104.2	89.9	75.6	40.1	32.2	24.2	33.3	20.8	8.7	0.00

Averages	Temperature (°F)			Humidity (%)			Total
	High	Avg	Low	High	Avg	Low	
	93.3	78.3	63.3	55%	36%	16%	

